[This is to us an important item.] "These symptoms tend to diffuse and invade neighboring groups of muscles. They have never the localization, the measured and purposed character of the contractions which belong to the lesions of the cortex. They frequently become transformed into permanent contractures.

"(*b*) The reflex vasomotor disturbances, due to irritation of the nerves of the dura mater, consist in spasms or congestive paralysis of the cerebral and ocular vessels, either on the same or the opposite side.

"These facts are important to pathologists, as they show the great influence of irritation of the nerves of the dura mater on cerebral vascular conditions, and on the organs of sense, and on the causation of secondary effects in cerebral traumatism, *i. e.*, on the congestions and inflammations of the cerebral membranes.

"II. Destructive lesions cause local anæsthesia of the dura mater."

I have made this long quotation from Duret because of its importance.

[To be Continued.]

AN EXPERIMENTAL AND CLINICAL STUDY OF AIR EMBOLISM.

[Continued from page 50.]

By N. SENN, M.D.,
OF MILWAUKEE.

EXPERIMENTS ON VENOUS AIR EMBOLISM.

THE injection of air was always made into the jugular vein. The neck was shaved and the surface disinfected with a 5 per cent. solution of carbolic acid. Ether was always used as an anæsthetic, the animal being kept fully under its influence until everything was in readiness to throw in the air, when the inhalation was suspended and the animal was allowed to come out from under its influence, for the purpose of studying the effects of the air on the heart and respiration.

independently of the effects of the anæsthetic. The vessel was freely exposed, usually in the lower part of the neck, by a parallel incision. After isolating it to the extent of from two to four inches the influence of the respiratory movements of the chest on the venous circulation was carefully studied. Then a hæmostatic forceps was applied to the distal portion of the vein. Below the point of compression the blood was forced out of the vessel between two fingers, and its return prevented by applying another pair of forceps to the proximal end of the exposed vein. We had thus a bloodless portion of vein between the two forceps, presenting a ribbon-like band. This was partially divided in an oblique direction for the purpose of facilitating the introduction of a canula. The canula was securely fastened in the vein by a ligature, when the proximal pair of forceps were removed, and, by compressing the bulb, the air was injected with force so as to imitate as nearly as possible the conditions present during the accidental introduction of air.

The canula was connected with a rubber bulb of known capacity by means of a rubber tube. After the completion of the experiment (if the animal survived) the vessel was divided completely, and both ends ligatured with catgut, and the wound closed with a continued catgut suture. The weight of the animal and amount of air injected were estimated accurately, in most instances.

Experiment No. 1. Sheep weighing 120 pounds. Left jugular vein. The vessel was opened in its lower third, but no air entered. A rubber tube was introduced for a distance of two inches, with a view of facilitating the spontaneous ingress of air; but this accident failed to occur. Air was injected at intervals of eight minutes in quantities of 30 c. cm. each, until the enormous amount of 480 c. cm. had been introduced.

After the first injection nothing was observed that indicated the presence of air in the veins or the heart. After the second dose a slight splashing sound could be heard over the cardiac region, which became louder and more distinct as the amount of air in the right side of the heart increased. The first serious symptoms observed were a tumultuous action of the heart, and difficulty in breathing, which became aggravated by every succeeding injection. Towards the end of the experiment, which lasted nearly two hours, the animal was attacked, at short intervals, by general convulsive movements. After the suspension of respiration the heart's action became very slow and feeble, and, at times, irregular. The immediate cause of death was plainly due to asphyxia, as manifested by the great dyspnœa and the cyanotic hue of all visible mucous surfaces.

On examination after death, a few air-bubbles and only a small amount of dark blood were found in the left ventricle. The right ventricle was arrested in the diastole, and contained a large quantity of very dark, almost black, spumous blood. Air-bubbles were found in a number of distant arteries of small size.

Experiment No. 2. Adult, large cat. In this instance the canula was introduced and tied in the left jugular vein. The heart was exposed before the injection was made, with a view of observing directly the effects produced by sudden inflation of the right cavities of the heart. Before the air was introduced the heart contracted regularly—artificial respiration being made for the purpose of preventing death by asphyxia. As soon as the right side of the heart was distended by the air, the left auricle and both ventricles ceased to contract, while the right auricle continued to pulsate. The pulsations were feeble and irregular. The coronary veins became filled with air-bubbles, presenting the appearance of a rosary. On opening the superior vena cava, air and frothy blood escaped, the right side of the heart collapsed, and all chambers of the heart commenced to contract regularly, and with considerable force. The pulsations continued for 15 to 20 minutes, becoming more feeble and irregular, and intermittent towards the last. After death, air was found in both venæ cavæ and the iliac veins. The left ventricle was completely empty. In this case, owing to the small size of the heart and the large amount of air introduced, the contractions of the right ventricle were arrested in the diastole while respiration continued. Death took place suddenly from mechanical over-distension of the heart.

Experiment No. 3. Dog, weight 65 pounds. Injected 30 c. cm. of air into left jugular vein. Churning sounds over cardiac region, loud and distinct. Heart's action became very tumultuous and intermittent. Respirations superficial and rapid. The animal was bled from the distal end of the jugular vein to the amount of 4 ounces, whereupon the heart's action became regular, and the respirations diminished in frequency. The vein was divided completely, and both ends were tied with fine catgut ligatures,—the wound being closed in the usual manner. For a number of days the dog appeared quite unwell, showed no disposition to eat, and acted very stupid, being inclined to sleep most of the time. In this case the intravascular pressure was promptly relieved by free bleeding, which enabled the heart to force the air through the pulmonary artery into the general circulation. The stupid condition of the animal was undoubtedly owing to embolism of the cerebral vessels, which disappeared after the disappearance of the air-emboli by absorption.

Experiment No. 4. Adult, medium-sized cat. Injected 15 c. cm. of air into left jugular vein. Heart's action arrested at once. Respirations, which were irregular, ceased a few moments later. The chest was opened at once. The right side of the heart was found enormously dilated and almost motionless. Coronary veins filled with air. The right ventricle was punctured with the needle of an aspirator and its contents withdrawn, when the pulsations were reëstablished. The ventricle was again inflated through the needle of the aspirator. Five minutes after this injection the pulsations numbered about 250 per minute. Five minutes later the left auricle ceased to contract, the movements of the right being irregular, and about 80 to the minute. After the lapse of another five minutes the pulsations of the ventricles were only 17 per minute; and a little later, all movements ceased.

This experiment demonstrates that the arrest of the heart's action was due to mechanical over-distension, as aspiration of the right ventricle was followed by regular and strong contractions in all cavities of the heart. The contractions were not the result of the mere mechanical irritation of the heart by the puncture, as other and equally severe irritants were previously applied without producing any effect.

Experiment No. 5. Dog, weight 35 pounds. Before operation respirations, 40; pulse, 140. Injected 20 c. cm. of air into right jugular vein. Convulsions followed, which lasted for about two minutes. Respiration rapid and stertorous. Pulse, 300. After five minutes the animal made repeated attempts to get up and walk, but invariably fell down on account of imperfect control over the movements, or paralysis of the posterior extremities. Half an hour later the animal was able to walk, but appeared very feeble. Pulse, 120; respirations somewhat accelerated. Recovery was complete. In this case the equilibrium of the circulation was soon restored, and the air in the right side of the heart passed through the pulmonary into the general circulation in a very short time, as was evident from the presence of symptoms indicative of embolism of some of the vessels in the cerebro-spinal centres.

Experiment No. 6. Dog, weight 75 pounds. Injected 60 c. cm. of air into the right jugular vein. Churning sounds, loud and distinct; heart's action labored. Respirations exceedingly rapid; later, stertorous. The animal recovered rapidly from the immediate effects of the air embolism, and was soon as well as before the operation.

Remarks. These experiments tend to prove the following statements; 1. A small amount of air in the right side of the heart in a healthy animal gives rise only to temporary symptoms, referable to the heart's action and the pulmonary circulation. 2. When air has been introduced into the right side of the heart in such quantities as not to arrest the contractions of the heart at once, it is forced through the pulmonary capillaries into the left side of the heart, by the contractions of the right ventricle. 3. The danger attending the insufflation of air into veins is proportionate to the amount of air introduced, as well as the capacity of the right ventricle to resist intra-cardiac pressure. 4. When a fatal dose of air has been introduced into the venous circulation, death takes place almost instantaneously, from arrest of the heart's action, or later, from suffocation. 5. Spontaneous ingress of air into a wounded, healthy jugular vein never occurred in these experiments, and must be considered a physical impossibility, as the resilient walls of the wounded vein collapse readily when exposed to atmospheric pressure.

Dogs weighing about 30 pounds would usually recover in a short time after an injection of 30 c.cm. of air, while double that amount constituted generally a fatal dose. Sheep required a proportionately larger dose to produce a fatal result. These experiments also tend to prove that animals of the same kind and species do not manifest the same degree of tolerance to the presence of air in veins. Young animals succumb more readily to its effects; in the adult animal the degree of tolerance depends on the more perfect development and contractile power of the right ventricle. In all cases where life was prolonged for a considerable length of time after the injection of air was made, and the ventricular contractions were not much impaired, bubbles of air were found in the left side of the heart, showing conclusively that the air must have passed from the right ventricle through the pulmonary capillaries.

In experiments Nos. 3 and 5, the well marked cerebral disturbances were undoubtedly produced by secondary air embolism of the vessels of the brain and spinal cord, since these disturbances disappeared after the removal of the emboli by absorption.

When the same amount of air was administered in one dose, it always proved more dangerous than when injected in divided doses, which simply means that during the interval between the injections sufficient time had elapsed for the right ventricle to force at least a portion of air through the pulmonary capillaries into the general circulation, thus preventing for a time at least a fatal degree of intracardiac pressure. The greater the development of the right ventricle, the greater the tolerance of the animal to the presence of air in veins. This statement is well exemplified by the fact that in horses a large amount of air is required to produce death, while in dogs a proportionately much smaller dose will result in death. This is, because in the former animals the right ventricle, from its proportionately greater strength, is more competent to perform an additional task. If death followed immediately after the injection, the dose was usually a large one, the heart's action having been suspended before respiration ceased, and on post-mortem examination the right ventricle and auricle were always found over-distended and tympanitic, containing a moderate amount of blood not intimately mixed with a large amount of air, while the left side of the heart was nearly or completely empty. If death occurred some time after the injection, great dyspnœa was observed, lividity of the mucous membranes, tumultuous action of the heart, and respiration ceased prior to cessation of the action of the heart, showing conclusively that death took place from carbonic acid intoxication. In these cases the necropsy revealed a lesser degree of distension of the right chambers of the heart, which invariably contained spumous blood, or blood intimately mixed with air. The pulmonary artery and its branches were filled with air and spumous blood; and bubbles of air and a small quantity of blood were present in the left ventricle. In opening the jugular vein, I have always noticed that the vessel would promptly collapse as soon as hemorrhage ceased, being transformed into a pale, round cord, in which the wound could be found only with great difficulty. Air was never seen to enter, even if the wound and a portion of the vein were kept patent with forceps or a rubber tube. I frequently arrested the column of blood in the vein by applying a compressing forceps above and opening the vessel below, thus creating the most favorable condition for the spontaneous entrance of air, but the result remained the same. It is, therefore, only reasonable to assume that air will enter spontaneously only in case a vein near the heart is wounded, the walls of which are prevented from collapsing by fixation of its tunics to adjacent, unyielding structures, or in case the vein walls themselves have lost their resiliency by previous pathological changes.

EXPERIMENTS ON ARTERIAL AIR EMBOLISM.

Experiment No. 1.—Medium-sized dog. The left carotid artery was exposed and isolated, and two hæmostatic forceps applied about two inches apart. The artery was divided between them, and the proximal end secured by a ligature. Into the distal end the canula of the injecting bulb was introduced and fastened with a ligature. When the animal had fully recovered from the anæsthetic, the forceps were removed, and 80 c. cm. of air were injected at once and with considerable force. The canula was then removed and the artery ligated. The animal collapsed almost instantaneously, and respiration was suspended for nearly two minutes. The animal appeared motionless and in a condition of profound stupor. Heart's action tumultuous and very rapid. Two minutes after the injection churning sounds were audible over the cardiac region. When respiration was re-established the movements of the chest were slow and irregular, gradually becoming slower and slower until after about fifty attempts they ceased entirely. The limbs were rigid, and the trunk in a position of opisthotonos. The heart continued to contract for about two minutes after respiration had ceased. All vessels leading to and from the heart were carefully ligated, and the organ removed and examined under water. The coronary veins contained bubbles of air. All cavities of the heart contained air, the largest amount being found in the left auricle. Coagula were present in all the chambers, except in the left auricle. The circle of Willis was distended with air, as were many of the smaller vessels of the brain and its membranes. The cerebral vessels were gorged with dark blood. The air injected into the carotid artery had evidently passed directly through the cerebral capillaries into the venous circulation, giving rise to venous and general air embolism. In the beginning, respiration was immediately arrested from temporary suspension of innervation, but was re-established as soon as the amount of air in the cerebral vessels had lessened sufficiently to allow a better blood supply. It, however, ceased definitely under symptoms expressive of extensive secondary embolism of the pulmonary artery.

Experiment No. 2.—Sheep; weight 90 lbs. Left carotid artery prepared as in previous experiment, only that the air was injected in a central direction, towards the heart. After the animal had recovered almost completely from the effects of the anæsthetic, 150 c. cm. of air were thrown in, and the proximal end of the artery was tied. The animal was at once thrown into a tetanic state, with rigid limbs and retracted neck. All reflex movements and sensations were completely suspended. The heart's action was irregular and tumultuous, and over the cardiac region distinct churning sounds were heard. Respirations exceedingly rapid. The mucuous membranes, accessible to sight, presented a strikingly pale and anæmic appearance. Death occurred in fifteen minutes, respiration ceasing first. Examination immediately after death showed the right ventricle greatly distended and tympanitic on percussion. It contained spumous blood, air, and a few small coagula. Left ventricle contained only a minute quantity of spumous blood and fine blood clots, adherent to the endocardium. Air emboli were found in almost all vessels throughout the body. Coronary arteries distended with air. Jugular veins contained more air than blood. Basilar artery and superior longitudinal sinus contained a large amount of air. The tongue and other distant organs extremely anæmic. Although this large quantity of air was thrown directly into one of the large arteries, it was forced into the smallest vessels, and through the capillaries into the veins and the right side of the heart by the powerful contractions of the left ventricle, giving rise to a combination of symptoms arising from arterial and venous embolism. Death was finally produced in a similar manner as if air had been injected directly into the veins. Some of the air had passed all the capillaries, and was found in the left side of the heart.

Experiment No. 3.—Medium-sized adult cat. With a view to ascertain how soon air would pass through the capillary vessels after injecting it into the carotid artery, the jugular on the opposite side was opened before the injection of air was made. About 15 c. cm. of air were thrown into the carotid artery in a peripheral direction. The animal was immediately seized with convulsions, and died in less than a minute. Respiration ceased first. Air was seen to escape from the wound in the jugular vein, and was also found in nearly all the vessels throughout the body. On opening the chest, the right side of the heart was found distended to its utmost and tympanitic on percussion. The contractions of the right auricle were twice as rapid as the ventricular pulsations. The movements of the left auricle were the same in frequency as the ventricular pulsations. The left auricle ceased to contract seven minutes after death. The right ventricle was punctured with the needle of an aspirator, and its contents removed, whereupon the contractions became much stronger.

8 min. after death ventricles contracted 44 times per min.;
10 " " " " " 30 " " "
12 " " " " " 16 " " "
18 " " " " " 16 " " "
29 " " " " " 6 " " "

Then all contraction ceased, and could not be restored by any kind of irritation. Right auricle ceased beating in ten minutes after death, but commenced to contract again nineteen minutes later, contracting 24 times a minute, the movements becoming more rapid and at times irregular for 48 minutes after death.

Experiment No. 4.—Dog; weight 35 lbs. Into the right carotid artery 80 c. cm. of air were injected in a proximal direction. The animal was seized at once with convulsions of a tetanic character, with the limbs extended and rigid. Involuntary discharges from bowels and bladder; sensation, motion and reflex actions suspended; pupils contracted; respirations very rapid; heart's action slow and labored. The left jugular vein was opened, and four ounces of blood were abstracted with the result of greatly improving the heart's action. Both vessels were ligated, and the wound closed. The animal was in a profound stupor, resembling complete anæsthesia, until death occurred 2½ hours after the operation. Half an hour after the injection, the pulse was 74; respirations 44 per minute. On opening the abdomen, the large veins were found very much dilated, and contained air. Large air-bubbles were also found in the pulmonary artery, internal mammary and coronary arteries. Small thrombi were found in many of the ultimate branches of the pulmonary artery. The right side of the heart was distended with spumous blood and air. The left ventricle was almost completely empty, the endocardial lining presenting many patches of sub-serous ecchymosis. Nearly all the vessels of the brain and the longitudinal sinus contained air. Cerebral and meningeal vessels engorged with blood. The animal died with marked symptoms of asphyxia. The tetanic rigidity of the extremities and the muscles of the trunk, as well as the remaining prominent cerebral symptoms, were produced by the intense collateral congestion, the result of obstruction of some of the smaller vessels by air emboli.

Experiment No. 5.—Adult dog; weight 20 lbs. Into the peripheral end of the right carotid artery 20 c. cm. of air were injected, after the animal had completely recovered from the anæsthetic. The dog collapsed almost immediately, and fell to the floor, perfectly unconscious, with extended and rigid limbs. Breathing exceedingly rapid, but gradually growing slower as consciousness returned. When the animal attempted to walk it staggered and frequently fell, having apparently lost the power of co-ordination in the posterior extremities. The pupils, at first dilated, later became very much contracted. After about two hours, the animal walked without difficulty, but respiration, as well as the heart's action, continued very rapid. The next day complete recovery had taken place. Aside from the cerebral and spinal symptoms, the arterial embolism in this case resulted in no serious consequences. The most threatening symptoms were referable to venous embolism, showing that most of the air had passed through the capillaries into the venous circulation and right side of the heart.

Experiment No. 6.—Adult dog; weight 22 lbs. Right carotid artery exposed, and 45 c. cm. of air injected towards the heart. Involuntary discharges from bladder and rectum. Pupils dilated; later contracted. Animal completely unconscious: anterior limbs extended and rigid; slight opisthotonos; breathing mostly abdominal. Churning sounds heard over heart a few seconds after injection, disappeared after eight minutes. Respiration ceased five minutes after the air was injected, but was again restored by artificial respirations and faradization of vagus and diaphragm. 23 minutes after the injection, pulse 128, respirations 24; 17 minutes later, pulse 105, respirations 26; 52 minutes after injection, pulse 120, respirations 20; 90 minutes after injection, pulse 180, respirations 20. At this time the animal made several unsuccessful attempts to rise, but relapsed into a comatose state, which continued until death, 15 hours after the operation.

At the post mortem examination, the arteries contained a good deal of dark, almost venous blood, interspersed with bubbles of air. Air was found in the uterine, ovarian, iliac and mesenteric arteries, and aorta; also in both venæ cavæ, pulmonary artery, and veins. Some of the smallest branches of the pulmonary artery were obstructed by thrombi. Right ventricle distended with very dark, almost black, frothy blood. Left ventricle firmly contracted and almost empty. Left auricle contained dark, spumous blood. Coronary arteries distended with air; internal mammary arteries and veins also contained it. Air was found in all the cerebral vessels and sinuses, which were distended with dark, fluid blood. Vessels of spinal cord were intensely congested, and contained numerous air bubbles. The mucuous membrane of the stomach presented 11 points of extravasation, the largest being circular and one inch in diameter. This case presented the most diffuse form of embolism, the emboli being found equally numerous and diffuse in the arterial and venous system. The multiplicity and diffusion can be satisfactorily accounted for, when we take into consideration the large amount of air which was injected, and the length of time which had elapsed from the time of insufflation until death occurred. The post mortem examination plainly indicated that death was produced by slow asphyxia. The primary unconsciousness and stupor were induced by the acute cerebral ischæmia; then a short period of consciousness returned as soon as the collateral circulation in the brain had become partially established, when again the animal became comatose from carbonic acid intoxication. The abstraction of blood relieved the threatening symptoms attending the arterial embolism, but failed in preventing death from asphyxia by secondary venous embolism.

Experiment No. 7.—Dog; weight 26 pounds. Injected 15 c. cm. of air into the right carotid artery, in a peripheral direction. The animal had a slight convulsion, and remained unconscious for about 20 minutes, when it rallied and was able to walk about the room with a slightly staggering gait. No complications followed the operation. In this instance the cerebral symptoms followed the insufflation instantly, but owing to the small amount of air injected, they were only of short duration. The air, passing the capillaries in a short time, entered the venous circulation, where it produced temporary disturbances in the pulmonary circulation.

Remarks. Injection of air into arteries produces well-marked and characteristic symptoms which point directly to a disturbance in the circulation of the brain and spinal cord. The most prominent symptoms are convulsions, coma, tetanic rigidity of the limbs and extensor muscles of the back. The coma resembles complete and profound anæsthesia. These symptoms follow the operation more quickly if the injection is made in a peripheral direction toward the brain. If the animal does not succumb to the primary effect of the air upon the brain and medulla oblongata, a series of symptoms succeed which announce the arrival of air in the veins and right side of the heart. All of the experiments show that it only requires a few seconds for the powerful contractions of the left ventricle to force at least a large portion of the air through the capillaries into the veins. The primary effect of embolism of the vessels of the brain is to produce acute cerebral ischæmia, the intensity of which depends upon the number and size of the vessels which have become obstructed by the air emboli. This anæmia soon gives rise to intense engorgement of the collateral vessels and the vessels behind the point of obstruction, and engorgement to such an extent that it often leads to rupture of capillary vessels and hemorrhage into the paravascular tissues. Unless the amount of air injected is sufficient to prove rapidly fatal by causing suspension of functions of the cerebro-spinal centres, the animal dies from asphyxia from embolism of the pulmonary artery—the same as though the air had been injected directly into the veins. The left ventricle, from its greater thickness and consequently more powerful contractions (as compared with the right ventricle), is better adapted to overcome the increased resistance, and hence the air is rapidly forced through the systemic capillary circulation into the veins and right side of the heart. On this account an equal amount of air injected into arteries is not so dangerous as when introduced directly into veins, as a certain percentage of it never reaches the veins and right side of the heart. Arterial air embolism is attended by an additional source of danger, which consists in the greater tendency to coagulation of blood in the heart and vessels, as was noted in several experiments.

DIRECT INTRA-CARDIAC INSUFFLATION OF AIR.

These experiments were made with a view of demonstrating by ocular inspection, that sudden over-distension of the cardiac muscles will arrest their contractility, and will thus produce paralysis of the heart in the diastole.

Experiment No. 1.—Medium-sized cat. After the animal was fully under the influence of ether, respirations and heart's action being normal, the chest was rapidly opened and the heart exposed. Its movements remained regular. From the sudden ingress of air into the cavity of the chest, the left lung collapsed, and it was found necessary, in order to prevent asphyxia, to make artificial respirations on the right side of the chest. The pericardium having been opened, the right ventricle was punctured with the needle of an aspirator, and air injected in sufficient quantity to distend the right chambers of the heart, which immediately ceased to contract. On emptying the right ventricle, by withdrawing the air and blood, the rhythmic movements of the organ were restored. These manipulations were repeated at least half a dozen times, and always with the same uniform and constant results. Half an hour after opening the chest all movements of the heart ceased. The heart was now removed and immersed in water at a temperature of 105° F., when it again commenced to pulsate at the rate of 120 beats per minute. After the lapse of about two minutes, it was removed from the warm water, still pulsating, and transferred to cold water, when all movements ceased instantaneously, and all efforts to revive them proved futile.

Experiment No. 2.—Large Maltese cat. Heart exposed, right ventricle punctured, and 11 c. cm. of air injected, with the result of immediately arresting the pulsations of the right ventricle. When the air was withdrawn, the regular movements were renewed. This experiment was repeated on both ventricles eight or ten times in the course of half an hour, with the same results. The auricles during all this time continued to contract. Ten minutes after the last puncture and evacuation, the ventricles were still pulsating.

Remarks. Both of these observations support the statement that sudden over-distension of any of the cavities of the heart by inflation of air will arrest its movements in the diastole, and that upon the removal of the increased intra-cardiac pressure, the movements of the organ are restored. It was found that by continuing the injecting force after the right ventricle had become distended, air could be forced readily through the pulmonary capillaries into the left side of the heart. In some instances one of the cavities of the heart was kept over-distended and at rest for at least a minute, and yet, on removing its contents, the rhythmic movements were resumed.

ASPIRATION OF RIGHT VENTRICLE FOR AIR-EMBOLISM.

Being satisfied of the fact that sudden over-distension of the right ventricle may and does produce paralysis in the diastole, it appeared reasonable to resort to some direct measure in removing the cause of over-distension in grave cases of venous air-embolism. Puncturing and aspiration of the right ventricle seemed to offer the best chances for accomplishing this object. In the following experiments artificial venous air-embolism was produced in the usual way, when the right ventricle was punctured with the needle of an aspirator two millimetres in diameter, and the contents of the right side of the heart removed by aspiration. The region over the heart was shaved and disinfected, and the exact point of puncture located before the animal was anæsthetized. The needle was always carefully disinfected by passing it through the flame of an alcohol lamp and immersion in carbolized water. When the puncture was made, the needle was advanced first only sufficiently deep so as to bury the opening in its point beneath the tissues, when a vacuum was created in the aspirator so that the entrance of the needle into the ventricle would be promptly announced by the escape of spumous blood. By following this precaution additional injury to the heart (by pushing the needle further than into the cavity of the ventricle) was avoided, and, at the same time, a prompt escape of blood was secured. Experience taught me that it was very important not to push the needle too deeply into the cavity of the ventricle, not only for fear of inflicting additional injury to the endocardial lining opposite the point of entrance. but more particularly with a view of removing the free air which would naturally occupy the highest point in the cavity, if it was not intimately mixed with the blood. The needle was always directed obliquely from below upwards, for the two-fold purpose of making a valvular wound in the ventricle and of avoiding unnecessary injury to the endo-cardium.

Experiment No. 1.—Dog; weight 31 lbs. Sixty c. cm. of air were injected into the left jugular vein. The animal was seized immediately with convulsions, followed by collapse; heart's action tumultuous; churning sounds over the heart were distinctly perceptible; respirations rapid and superficial. Right ventricle was punctured and 120 c. cm. of spumous blood were withdrawn. Pulsations of heart became more feeble, and as respirations had ceased and could not be restored, the chest was opened. The right ventricle was found moderately dilated and still contracting. Slight contractions of lower portion of left auricle. Left ventricle contracted, but without motion. The needle of the aspirator was then introduced into the right auricle, which was distended and tympanitic. After emptying it, it commenced to contract. All contractions ceased half an hour after the air was introduced. Faradic currents had no effect upon the heart after it had ceased to contract. The pericardium contained air in considerable quantity and about 4 c cm. of fluid blood. Air was found in the right side of the heart, the left ventricle, coronary veins, and in the large veins in the immediate vicinity of the heart. Puncture about an inch from septum and nearly equi-distant between the apex and base of heart. No injury of endocardium on opposite side.

Experiment No. 2.—Sheep; weight 95 lbs. Before operation, respirations 86; pulse 140. Injected 150 c. cm. of air into left jugular vein, which was immediately followed by convulsions and involuntary discharges. Aspiration of right ventricle, and removal of 150 c. cm. of spumous blood. As the animal still presented an asphyxiated appearance, the ligature was removed from the distal end of the jugular vein, and about 120 c. cm. of blood were allowed to escape. The animal showed no signs of improvement, and died 5 minutes after the injection was made, having made only five attempts at respiration during the time. Pericardium contained a small coagulum and a few bubbles of air. Right ventricle, distended and tympanitic, contained spumous blood. Two punctures were found over the middle of the right ventricle about one-half cm. apart; the second was made during the convulsive movements of the animal, which necessitated a partial withdrawal and re-introduction of the needle. On the inner surface each puncture was hermetically sealed by a minute thrombus, which projected only very slightly into the cavity of the ventricle. In the left ventricle, which was firmly contracted and empty, a small filiform coagulum projected through the aortic orifice into the aorta.

Experiment No. 3.—Old dog; weight 40 lbs. Injected 45 c. cm. of air into left jugular vein; churning sounds over heart, loud and distinct; heart's action labored; respirations exceedingly rapid; no convulsions, but profound coma and involuntary discharges. A little more than one minute elapsed between the introduction of air and aspiration, during which time the heart's action became more and more embarrassed, and all of the symptoms became so grave that death seemed unavoidable. But as the needle reached the heart, a slight impulse was imparted to it by the feeble pulsations, and 120 c. cm. of air and spumous blood were removed. The heart's action improved immediately, but the dyspnœa, although less severe, was still quite prominent. Consequently, an additional 120 c. cm. of blood were allowed to flow from the peripheral extremity of the jugular vein, which promptly relieved the urgent symptoms. Ten minutes after the injection, respirations were 240 per minute; four minutes later 360, and after eight minutes more 120. After 40 minutes the stupor disappeared, and the animal was able to walk. One hour after the operation, respirations were 20 and pulse 160 per minute. At this time the animal walked home, a distance of nearly two miles, and subsequently suffered no inconvenience from the operation.

Experiment No. 4.—Dog; weight 75 lbs Injected into left jugular vein 90 c. cm. of air, which produced intense difficulty in breathing and profound stupor. Sensation and reflex movements suspended. Heart's action exceedingly feeble and rapid. Churning sounds distinct. The aspirator and needle were kept in readiness to be used promptly on the approach of symptoms indicative of impending death. Two minutes after the injection the animal was apparently in a dying condition, when the needle was plunged into the right ventricle, and from its rapid oscillations it was apparent that the heart's action had not entirely ceased, but was very rapid and feeble. As quickly as possible 180 c. cm. of spumous blood were withdrawn, which promptly relieved the most urgent symptoms, but as the respirations still remained rapid and labored, the ligature was removed from the distal end of the jugular vein, and 240 c. cm. of blood were allowed to escape. Eight minutes later, after the injection, the churning sounds over the heart were still present, but faint. Respirations 144; pulse 130. When the animal had recovered from the immediate effects of the operation, it was noticed that the posterior extremities could be moved only with difficulty, the gait being slow and staggering. For twelve hours the animal was dull and stupid, remaining in the same place without change of position. The drowsiness continued for 36 hours, after which the animal became lively, and went on to complete recovery without any further interruption. In this case it was apparent that the animal would have died from the large volume of air which had been injected, but for timely use of the needle and aspirator. Three weeks after the experiment the animal, being in perfect health, was killed by an arterial injection of air. No signs of pericarditis, endocarditis, or myocarditis. Puncture in ventricle indicated by a minute faint cicatrix.

Experiment No. 5.—Old dog; weight 25 lbs. In this case the aspirator was used a few seconds after the insufflation of air was made, and the result shows how important it is to withdraw the air from the ventricle before it has had time to escape into the pulmonary artery. Immediately after the injection of 90 c. cm. of air into the left jugular vein, the animal became comatose. Respiration exceedingly rapid, and heart's action imperceptible. The right ventricle was punctured at once, and as soon as a part of its contents had been removed, the impulse of the heart was imparted to the needle, which could be distinctly seen and felt. Spumous blood and air to the amount of 150 c. cm. were withdrawn. The dog rallied rapidly after the aspiration, being able to walk in less than half an hour. He manifested no pain or discomfort from the air embolism or operation. The volume of air in this case was three times as large as in the previous experiment, when the weight of the animals is compared. The immediate effects of the air were expended upon the heart, as was made evident by the temporary cessation of its pulsation, and yet death was prevented by the prompt removal of the excessive intracardiac pressure. The recovery was more rapid than in the previous cases, from the fact that not so much air had passed into the pulmonary artery, and more was removed by aspiration. Two weeks later, the animal being in perfect health, 60 c. cm. of air were injected into the right jugular vein, which produced death in a few minutes, showing conclusively that the recovery, after the first insufflation, was due to the aspiration. Cicatrix of puncture plainly visible. No signs of inflammation in the pericardium, endocardium, or substance of the heart.

Experiment No. 6.—Young dog; weight 28 lbs. In this experiment 120 c. cm. of air were thrown into the left jugular vein, in divided doses of 30 c. cm. each, in rapid succession. During the third injection the animal howled and became comatose, and immediately after the last injection the heart's action ceased, and respirations were reduced to a few irregular gasps. The right ventricle was punctured, and 120 c. cm. of spumous blood and air were withdrawn, without producing any effect upon the heart. Artificial respiration was resorted to, without any better result. The chest was opened at once. The pericardium contained 4 c. cm. of dark, venous blood and a few air bubbles. Right auricle continued to contract 48 times per minute. Left auricle and ventricle were distended and contained spumous blood. The needle had punctured the right auricle, instead of the ventricle. All muscles, voluntary and involuntary, reacted promptly to the faradic current, but it had not the slightest effect upon the heart.

Experiment No. 7.—Young dog; weight 10 lbs. Injected 45 c. cm. of air into the left jugular vein. At the end of the injection the dog howled, and the heart's action ceased almost instantaneously. The right ventricle was aspirated, and 60 c. cm. of spumous blood were withdrawn. Artificial respiration was performed, and the faradic current was applied, when the dog made a few ineffectual attempts at respiration before he died. On examination, the pericardium was found to contain a slight amount of dark, fluid blood, and a few air bubbles. Both auricles contracted about 48 times in a minute. Right ventricle arrested in diastole. Puncture was found near base of ventricle. Right ventricle was again aspirated, and the faradic current was applied to the heart and the needle, without producing the slightest effect. Right ventricle and pulmonary artery contained spumous blood. Left ventricle contracted and nearly empty.

Experiment No. 8.—Adult dog; weight 24 lbs. Before operation, respirations 80, pulse 100 per minute. Injection of 30 c. cm. of air into left jugular vein. Immediately after injection, great restlessness, dyspnœa, and tumultuous action of heart; churning sounds loud and distinct. Removed 90 c. cm. of spumous blood from right ventricle by aspiration. After the aspiration, the improvement in respiration and pulse was marked. Recovery complete and not attended by any complications.

Experiment No. 9.—Same animal as in experiment No. 3. Animal in perfect health. Time since first operation, 3 weeks. Injection of 40 c. cm. of air into right jugular vein. Symptoms the same as before. At the end of 3¼ minutes the pulsations of the heart ceased, and the respirations were nearly suspended. The right ventricle was now punctured, and 250 c. cm. spumous blood were removed. No motion imparted to needle. Faradization and artificial respiration were ineffectual in restoring either the heart's action or respiration. On examination, 30 c. cm. of dark, fluid blood were found in the pericardium. No evidences of inflammation from former puncture. Right ventricle moderately distended with a clot of spumous blood. Point of second puncture one-half inch from coronary artery. The location of first puncture was marked near the base of right ventricle by faint minute cicatrix upon the pericardial surface, while the endocardium, at a corresponding point, showed an old circumscribed spot of ecchymosis, but no evidences of inflammation. Left ventricle contained no air, and only a minute quantity of fluid blood. Both auricles nearly empty. Pulmonary artery contained air and spumous blood. This experiment demonstrates positively and conclusively the value of early aspiration of the right ventricle in venous air embolism, where death is threatened by over-distension of right side of the heart, or by asphyxia. In the former experiment a larger amount of air was injected, but the animal was saved by an early aspiration, by which a large amount of air was removed before it had time to accumulate in the pulmonary artery. It also illustrates the utter uselessness of resorting to any kind of mechanical interference after a fatal dose of air has once passed beyond the semi-lunar valves into the pulmonary artery. In such instances the air has passed beyond our reach, and will inevitably lead to a fatal result by asphyxia.

Experiment No. 10.—Adult dog; weight 18 lbs. Injection of 60 c. cm. of air into the left jugular vein. Immediate collapse; churning sounds distinct; aspiration of 100 c. cm. of air, and spumous blood from right ventricle. Three minutes after the insufflation, respiration and heart's action had ceased. No air or blood found in the pericardium. Needle puncture equidistant between base and apex of right ventricle, and about 2 cm. from septum. Right auricle contracting feebly 40 times a minute. Right ventricle dilated; fibrillary contractions at apex only. Right ventricle and pulmonary artery contained spumous blood. Left auricle and ventricle contained only a slight amount of fluid blood and a few air bubbles.

Remarks. These experiments serve to illustrate the following interesting points in pathology and surgery:

1. The heart can be punctured with a perfectly aseptic, medium-sized needle of an aspirator, without any great immediate or remote danger.

2. Aspiration of the right ventricle for venous air-embolism, when done early enough (before a fatal dose of air has been forced into the pulmonary artery), must be considered in the light of a life-saving operation.

Although the needle used in all of these experiments was two millimetres in diameter, the hemorrhage into the pericardium was never sufficient in quantity to prove a source of danger. The largest quantity found was 30 c.cm. (in experiment No. 9). In a number of cases no trace of blood was found in the pericardium. Against my expectations the same observations were made in regard to air. In one case the pericardium contained about 60 c.cm. of air, while in most cases only a few isolated air-bubbles were seen, while in others no trace of it could be found. In all cases where the animal survived the operation and was killed from a few days to three weeks subsequently, no trace of inflammation could be found either in serous membranes, muscular tissue or adjacent organs. Even adhesion between the parietal and visceral layers of the pericardium at the point of puncture never occurred. The point of puncture was usually marked by a faint, minute cicatrix in the visceral pericardium, unaccompanied by any pathological changes in the substance of the heart. We take it for granted that if effusion of blood or air occurred into the pericardium in the animals which recovered, these adventitious substances caused no irritation, but were promptly removed by absorption.

With the exception of the subject of experiment No. 8, it may be safely assumed that all of the animals would have died, had aspiration not been performed, so that the operation saved at least three of the animals out of ten, or the whole number of experiments. The most conclusive proof of this statement was furnished by the subjects of experiments Nos. 3 and 5, as these animals died during subsequent experiments from the introduction of a much smaller quantity of air. The question naturally arises, Why were not all of the animals saved by the aspiration? In reply, it may be stated, that the amount of air injected in most instances was large—more than was necessary to produce a fatal result. Another element of failure consisted in the postponement of the aspiration until a fatal dose of air had passed beyond the reach of the aspirator. To prevent death by air-embolism it is essential to remove the air from the right ventricle as soon as possible after its entrance, before a fatal embolism of a pulmonary artery has had time to take place. In some of the experiments a fatal result might have been probably prevented by removing a larger quantity of air and blood with the aspirator, as in some instances the condition of the animal was improved by a subsequent venesection from the jugular vein.

CATHETERIZATION AND ASPIRATION OF RIGHT AURICLE FOR VENOUS AIR-EMBOLISM.

In grave cases of accidental air-embolism it would be a desideratum to be in possession of some means by which the air could be removed directly from the right side of the heart in the shortest possible space of time and with the simplest implement. An aspirator is not always at hand, and less frequently in a proper condition to be used on such short notice. It appeared to me, that inasmuch as the accidental introduction of air usually takes place through wounds in one of the jugular veins, a catheter might be introduced through the wound into the vein and from there passed directly into the heart, and through it the air and spumous blood could be withdrawn by aspiration. A catheter is almost always at hand, and its introduction could require only a few moments of time. The following experiments were made to test the feasibility of this procedure:

Experiment No. 1.—Adult dog; weight 24 lbs. The right jugular vein was opened, and 60 c. cm. of air were introduced in the usual way. The breathing became very difficult, and the heart's action labored. The animal was comatose; pupils dilated. As soon as it could be done, a No. 6, English scale, gum elastic catheter, which had previously been made aseptic, was introduced into the wound and passed into the heart, a distance of 15 cm., and, with an exhausting syringe, 25 c. cm. of air and spumous blood were removed. The animal recovered rapidly from the immediate effects of the air embolism and operation, and subsequently manifested no symptoms of disease.

Experiment No. 2.—Young dog; weight 30 lbs. Injected 100 c. cm. of air into left jugular vein. The heart's action ceased almost instantaneously. The same catheter was introduced and pushed forward a distance of 18 cm., and about 120 c. cm. of air and spumous blood were withdrawn by the mouth. At this time respiration ceased, and as no pulsations of the heart could be felt, the chest was opened at once. Fibrillary contractions of right ventricle, which was distended and tympanitic. Left auricle and ventricle contracted and motionless. Right auricle contracted regularly 80 times per minute. Faradic and galvanic currents had no effect on ventricles. Right auricle responded to a galvanic current, slowly and interruptedly. The catheter was again introduced, and its course observed as it entered the right auricle. It was found impossible, by any manipulations, to pass it from the auricle into the ventricle. In every instance it passed from the right auricle directly into the inferior vena cava. The right side of the heart was filled with water, to test the possibility of the moving fluids from the right auricle, without introduction of the catheter into the chamber. A catheter with an open extremity was used. No amount of suction force succeeded in moving any of the fluid, until the open end of a catheter reached the auricle, when both chambers could be readily emptied. As long as the end of the catheter remained in the vein, the walls of the vein in front of the catheter would invariably collapse and close the opening in the catheter completely, on applying suction force. This satisfied me that, in order to remove air or blood from the right side of the heart, it is necessary to introduce the catheter as far as the auricle. It was also evident that, in case the catheter be introduced too far, its distal end would pass into the inferior vena cava, and on aspiration, only venous blood would be withdrawn, not air and spumous blood, from the right chamhers of the heart, for the removal of which the procedure was intended. On opening the right side of the heart, a large spongy clot of spumous blood was found in the right auricle, which extended for some distance into the ventricle. Left ventricle contained only a small amount of fluid blood and a few air bubbles. As the heart's action had ceased before catheterization, death was undoubtedly due to the insufflation of air, and not to the formation of a thrombus in the heart.

Experiment No. 3.—Adult dog; weight 20 lbs. Injected 30 c. cm. of air into right jugular vein. Catheterization and aspiration of right auricle, by which 90 c. cm. of air and spumous blood were removed, when catheter became impermeable by a thrombus in its interior, and was removed. Before emptying the right side of the heart, the animal was comatose; breathing and heart's action exceedingly rapid. After aspiration, rapid movement and complete recovery. If the catheter, in this instance, had been permitted to have remained longer in the auricle, the thrombus which formed in the anterior of the instrument would undoubtedly have increased rapidly, and would have extended to the auricle, in which event death from thrombus would have been unavoidable.

Experiment No. 4.—Old dog; weight 40 lbs. Before operation, respirations 16, pulse 100 per minute. Injection of 90 c. cm. of air into left jugular vein. Passed a No. 5 Nélaton's catheter into the right auricle, a distance of 27 cm., and removed 250 c. cm. of air and spumous blood. Immediately after the insufflation the animal uttered a howl and became comatose. Pulse 250 per minute; respirations so rapid that they could not be counted. Seven minutes after catheterization, heart's action very irregular, tumultuous, and about 300 beats per minute. Two minutes later respiration ceased, after which the heart's action became slow and feeble, only to cease a few seconds later. Internal mammary and coronary veins filled with air. Left side of heart contained a small amount of bright, red, frothy blood. Right ventricle, moderately dilated, showed fibrillary contractions. Superior and inferior vena cava, right auricle and ventricle contained a continuous, soft thrombus, the oldest portion of which corresponded to the superior vena cava. The upper portion of the clot in the inferior vena cava contained air. Death, in this instance, was due to the formation of a thrombus.

Experiment No. 5.—Adult dog; weight 25 lbs. Injection of 60 c. cm. of air into left jugular vein produced immediate collapse, distressing dyspnœa, and great rapidity and irregularity of heart's action. The dog howled, when the heart's action ceased and respiration became gasping. Some delay was experienced in the introduction of the catheter, and when the instrument was in place all signs of life had disappeared. About 50 c. cm. of spumous blood withdrawn, without any signs of improvement. Artificial respiration and faradization were resorted to, without producing the slightest impression. On opening the chest, it was observed that the right auricle contracted about 30 times per minute. Irregular fibrillary contractions of apex of right ventricle. Right side of heart moderately distended with spumous blood. No thrombus. Left ventricle almost empty.

Experiment No. 6.—Adult dog; weight 15 lbs. Injection of 60 c. cm. of air into right jugular vein. In this case the catheter was connected with a rubber tube three feet in length, which was kept in water; then the instrument was pushed along the jugular vein into the right auricle. The injection of air was followed by the most urgent and distressing symptoms. Only a small amount of dark, venous blood escaped through the rubber tube until the catheter reached the right auricle, when a gush of spumous blood escaped from the tube under water. As the blood did not continue to escape, about 60 c. cm. of spumous blood were withdrawn. After the aspiration, the symptoms improved rapidly, and within 25 minutes, with the exception of a slight excess in the respiratory movements, the animal appeared to be perfectly well. The ultimate recovery was complete, and not disturbed by any complications.

Experiment No. 7.—Adult dog; weight 48 lbs. Before operation, pulse 150, respiration 28. Injection of 120 c. cm. of air into right jugular vein. The animal howled and collapsed. Respirations increased at once to 100 per minute. Heart's action tumultuous, and churning sounds loud and distinct. Passed a Nélaton's catheter into the right auricle, and aspirated 360 c. cm. of air and spumous blood; no signs of improvement followed, and in fifteen minutes the animal was dead. At the post mortem examination, the internal mammary veins were found distended with air. Right side of heart tympanitic and distended. Slight fibrillary contractions of right auricle. Apex of right ventricle contracted regularly 22 times per minute. Coronary veins filled with air. A thrombus had formed, which extended from the superior vena cava into right auricle, ventricle, and for a distance of 25 cm., into the inferior vena cava. Pulmonary artery contained no thrombus, but was distended with air and spumous blood. Left ventricle contracted, contained a small amount of fluid blood and air bubbles. It was quite evident that the thrombus had primarily formed around the catheter, and by new additions it finally reached the distal portion of the inferior vena cava. Death was produced by thrombosis.

Remarks. The therapeutical value of catheterization and aspiration of the right auricle for air-embolism is made apparent by the following tabular arrangement of experiments:

No. of Exp	*Weight of Animal.*	*Amount of Air Injected.*	*Am't of Air and Blood Removed.*	*Result.*	*Cause of Death.*
1	24 lbs.	60 c. cm.	250 c. cm.	Recovery.	
2	30 lbs.	100 c. cm.	120 c. cm.	Death.	Thrombosis.
3	20 lbs.	30 c. cm.	90 c. cm.	Recovery.	
4	40 lbs.	90 c. cm.	250 c. cm.	Death.	Thrombosis.
5	25 lbs.	60 c. cm.	50 c. cm.	Death.	Air Embolism.
6	15 lbs.	60 c. cm.	60 c. cm.	Recovery.	
7	48 lbs.	120 c. cm.	360 c. cm.	Death.	Thrombosis.

From this table it will be seen that, of seven animals subjected to the the operation, three recovered and four died. The amount of air injected in the subjects of experiments Nos. 1 and 6 was sufficient to destroy life, so that we can safely assume that the animals would have died, but for the speedy resort to catheterization and aspiration. In the subject of experiment No. 3 recovery might have taken place without the operation, as the relative quantity of air was much smaller. In the four fatal cases death was produced only once from the presence of air, while the direct cause of death in the remaining three was due to thrombosis. All possible precautions were exercised to prevent the accident. The catheter was made aseptic by thorough cleansing and immersion in a five per cent. solution of carbolic acid. Before the operation the instrument was kept ready for use in an alkaline solution of the temperature of the body, and yet this accident happened in three of seven cases. It is now asserted that the introduction of aseptic bodies into the circulation does not give rise to thrombosis, and it may be possible that some of the instruments, in spite of the pains taken to render them aseptic, were still not in a fit condition to be used for such a purpose. Catheterization and aspiration of the right auricle for air-embolism compare favorably with puncture and aspiration of the right ventricle as a life-saving procedure, but the former operation is more dangerous on account of the tendency to the formation of a thrombus within or around the catheter. If this formation of a thrombus could be avoided with certainty, catheterization and aspiration of the right auricle would recommmend itself as the most expedient and reliable therapeutic agent in cases where life is threatened by air-embolism.

[To be Continued.]